OPTICAL PROPERTIES OF LOW-DIMENSIONAL SEMICONDUCTORS

by

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low dimentional Semiconductors - Scanning Electron microscopy
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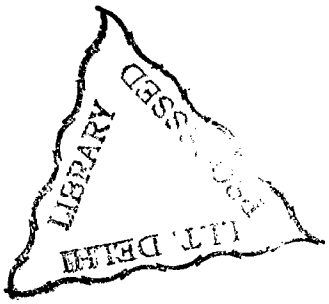
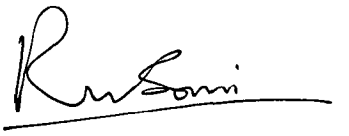


CERTIFICATE

This is to certify that the thesis entitled, **"OPTICAL PROPERTIES OF LOW-DIMENSIONAL SEMICONDUCTORS"**, being submitted by **Mr. Sanjay Kumar Mohanta** for the award of the degree of **Doctor of Philosophy** to the Indian Institute of Technology Delhi, New Delhi, is a record of bonafide research work he has carried out under my guidance and supervision.

In my opinion, the thesis has reached the standard fulfilling the requirements of all regulations related to the degree. The results contained in this thesis have not been submitted to any other University or Institute for the award of any degree or diploma.



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ABSTRACT

Optical properties of low-dimensional semiconductors, in the form of quantum dots and porous materials grown under different processing conditions by low-energy Ar^+-ion irradiations and laser induced etching, are studied using photoluminescence (PL) and Raman spectroscopy. The emphasis is placed on modification in electronic state, carrier confinement and lattice vibration in grown structures. To explore the shape and size of the low-dimensional structures, a detail morphological investigation is carried out by Scanning Electron Microscopy (SEM) and Atomic Force Microscopy (AFM). The study of influence of rapid thermal annealing (RTA) on the morphological and optical properties of such low-dimensional structures is also presented.

Detail morphological investigations of the nanopatterned InP, GaAs and Si surfaces reveal that the shape and size of the nanoislands are strongly influenced by growth parameters such as energy, dose, and incidence angle. For InP surface, the sizes of dots are around 50 to 130 nm and height around 25 – 30 nm for Ar^+-ion of dose in the range 1×10^{17} to 1×10^{18} cm^{-2} and energy 50 and 100 keV with normal and off-normal incidence. The average sizes of the dots are about 25 – 35 nm and height around 3.5 – 5.0 nm for Ar^+-ion irradiated GaAs surface. The swelling of the Ar^+-irradiated GaAs surface, observed at a highest energy and dose (100 keV and 1×10^{18} cm^{-2}), is attributed to the ion-beam induced porosity in the amorphized GaAs surface. The size of the dots are around 25 – 60 nm, and height 6–13 nm, for nanopatterned Si surface. The influence of rapid thermal annealing (RTA) on morphology of the patterned surface shows clustering of the surface nanodots, and decrease of dot height. The clustering of the patterned surface observed upon RTA is due to the degradation of the near surface, caused by over heating.

The formation of large craters on the patterned GaAs surface upon RTA is a consequence of decomposition of the porous GaAs within amorphous matrices.

The SEM investigation of laser-induced etched porous GaAs surfaces shows the porous structure with well-packed structures of randomly oriented pores separated by thin column walls, and are dependent on laser power density, irradiation time, and laser wavelength. The formation of porous structure occurs due to photochemical etching of semiconductor surface accomplished by the charge transfer at semiconductor-electrolyte interface, which initiates the chemical reaction. The size of the pore wall decreases with increase in etched laser power density, laser energy, and irradiation time.

The Raman scattering from Ar^+-ion irradiated nanopatterned InP, GaAs and Si surface shows downward shift and asymmetry broadening of first-order optical modes, which increases with increase in ion dose and energy, and decreases with increase in incidence angle with respect to surface normal. The downward shift of optical mode is due to the confinement of phonons within the nanocrystallites along with surface nanodots, and the broadening is due to the nanocrystallites size distribution. The ion-induced amorphization also leads to additional asymmetric broadening of the optical modes, which is large for nanopatterned GaAs surface and small for nanopatterned InP surface, and is due to the difference in their thermal conductivity.

The influence of RTA on Raman spectra from Ar^+-ion irradiated nanopatterned surface shows the reverse shift of the optical modes with annealing temperature, and related to the reduced contribution of the amorphous fraction and disordered-activated modes. The annealing causes the transformation from micro/nano-crystalline and amorphous phase of the irradiated surface to crystalline phase, which increases the

correlation length of the phonons contributing to the optical modes, and shows reverse shift. The upshift in optical modes at higher annealing temperature ocuured from the patterned surface is associated with the presence of complex interfacial stress, associated with the removal of crystal defects with RTA .

The Raman spectra from laser induced etched n-GaAs show downward shift and broadening of the first-order optical modes, which increase with increase in etched laser power density and irradiation time and decrease with laser wavelength. The maximum downward shift is observed from the porous GaAs etched with power density 2.26 W/cm^2, irradiation time 90 min and laser wavelength 514.5 nm. The downward shift of the Raman peak is attributed to the confinement of phonons in the particles of nanometer sizes and the broadening is because of the large size distribution of the porous material in the etched area.

The room temperature photoluminescence exhibits a blue shifted PL band, from nanopatterned InP surface produced by Ar^+-ion, compared to the band edge emission from bulk InP. The blue-shifted emission band is due to confinement of carrier in InP quantum dots. The quenching of the band edge emission from irradiated surface occurs due to the formation defects caused by ion-induced disorder, and acts as effective steps in one phonon non-radiative recombination of photoexcited carriers. The influence of annealing shows the enhancement of the band-edge emission from patterned surface with improved optical quality, due to the removal of ion-induced surface disorder.

The study of photoluminescence (PL) from the photosynthesized porous n-GaAs shows blue shifted PL band in the visible region with energy larger than that of the band edge emission. The origin of the blue shifted PL band is due to the confinement of

carriers within the pore walls, and broadening is because of their size distributions within the porous structures. The maximum blue shift of 0.7 eV is observed from the sample etched with power density 2.26 W/cm^2, irradiation time 90 min, and laser wavelength 514.5 nm. The asymmetry towards higher wavelength side of the sample etched with power density 2.26 W/cm^2 and irradiation time 90 min is because of larger distribution of particle size towards higher wavelength. The bimodal blue-shifted PL band, with peak position at 670.6 nm (1.85 eV) and 585 nm (2.12 eV), is observed for the sample etched with power density 3.96 W/cm^2 for irradiation time 45 min.

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